MODELLING THE IMPACTS OF PESTICIDES ON ECOSYSTEMS AND DRINKING WATER QUALITY USING THE STORM PESTICIDE MODEL™

ROD WIESE

Storm Consulting Pty Ltd, 7/84 Church St, Richmond, VIC, 3121 Australia, rod@stormconsulting.com.au

NICK O'CONNOR

Ecos Environmental Pty Ltd, PO Box 1064G, Balwyn North, VIC, 3104, nick.oconnor@ecosec.com.au

A detailed quantitative hydrological and chemical transport model was developed for assessing the risk of pesticides on aquatic ecosystems and drinking water. The STORM Pesticide Model™ is an MS Excel based program that integrates hydrology and pond hydrodynamics with pesticide mass balance in continuous simulation at 6 minute increments. The model predicts the behaviour of pesticide wash-off accounting for application rates and mixing in various water bodies for a range of rainfall events. The hydrology engine drives the mass balance of pollutants that are washed off the catchment according to the pesticide application (rate and area). Calculation of flow volumes and degradation characteristics produce final pond concentrations and outflow concentrations for various pesticides. These are then compared with various water quality criteria to determine compliance in a risk management framework. What results is the establishment of sustainable rates of pesticide application.

1 OVERVIEW OF MODEL

The STORM Pesticide Model has been developed to address an existing knowledge gap in stormwater management concerning relationships between the transportation and persistence of pesticides, and local hydrology. The driver to create the model was motivated by a need to quantify pesticide runoff into a sensitive waterbody - in this case the Yarra River. These modelled values were then compared to the recommended guideline values for both drinking water and ecosystem protection.

The STORM Pesticide model is a Microsoft Excel based program that integrates hydrology with pesticide mass balance in a continuous simulation at 6 minute increments. It can predict the peak and average concentration of pesticides leaving a site, as well as those present in ponds/waterbodies within the assessment area. The model combines hydrologic catchment characteristics and surface areas with discrete rainfall events to generate runoff flows. They are based on standard industry algorithms used commonly in the industry to estimate runoff flow rates and volumes. The storage ponds are also embedded in the model to incorporate mixing characteristics for dilution, the pond's connection with catchments and also the sequence of drainage of upstream ponds. The hydrology engine drives the mass balance of pollutants that are washed off the catchment according to the pesticide application rate and area, pesticide affinity for soil organic carbon (i.e. partitioning rate), and the pesticide degradation characteristics to produce final pond concentrations and outflow concentrations of the pesticide.

By relating pesticide concentrations at the site discharge location to appropriate environmental and drinking water guidelines, the model has become a decision making tool to support practices for informed risk management. Figure 1 describes the overall process of the STORM Pesticide model with key assumptions. Each relevant model variable is described in further detail through this extended abstract.

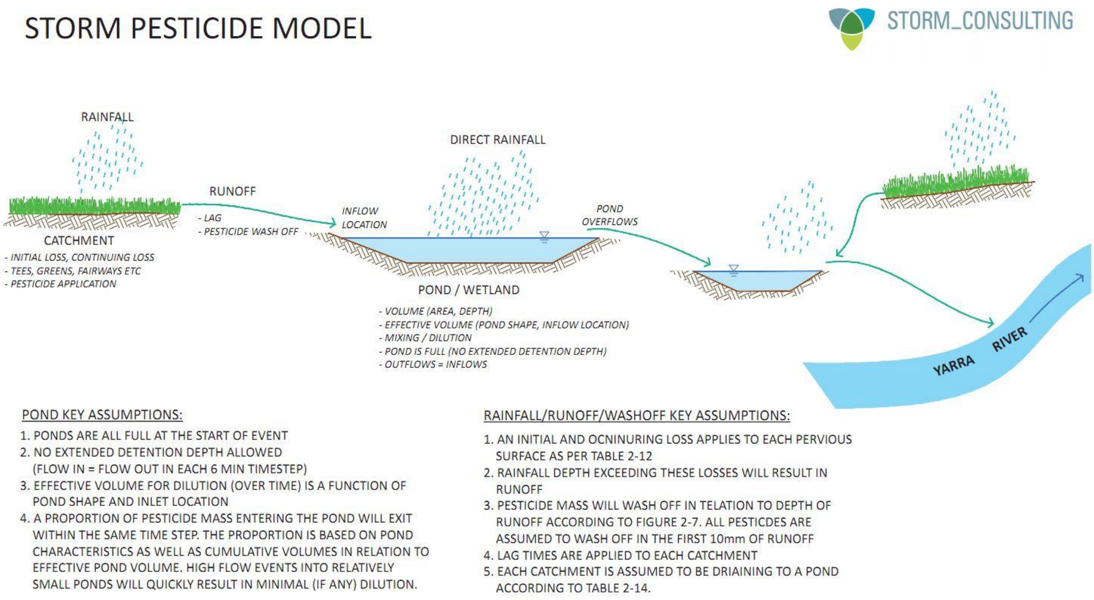


Figure 1. STORM Pesticide Model schematic

2 HYDROLOGY ENGINE

2.1 Rainfall data

Six minute interval pluviograph data obtained from the Bureau of Meteorology (BoM) were used to determine individual storm events. These data spanned 1965 to 2006 and were recorded at the Croydon Council Depot (station 86234), located approximately 10.6 km from the site.

Both the 5 year and 10 year ARI rainfall events were theoretically derived for the purposes of validating the hydrology engine.

2.2 Catchment nodes

The Model accommodates up to 24 sub-catchments that can each contain seven different surface characteristics to define the hydrology and pesticide application. Associated with each of these surfaces is an initial and continuing loss which is commonly used in hydrology models. These variables enable estimation of runoff from each surface within the catchments. The loss which occurs at the beginning of the storm before run-off is generated is known as the initial loss. The continuing loss represents the average loss over the remaining storm duration.

The initial and continuing losses of these seven defined surfaces are assumed constant across all catchments. However, the combination of contributing surfaces, catchment shape and size ultimately influences the catchment's hydrologic response. The time of travel and time of concentration incorporates the spatial characteristics of the catchment using fundamental hydrological principles. This is a common concept in hydrology which influences the catchment response and outflow hydrograph for given rainfall events.

2.3 Pond nodes

The model can accommodate up to 10 ponds which provide mixing and dilution opportunity for pesticides in inflows. The ponds are assumed to be 100% full prior to a rainfall event. It is also assumed that there is no flow routing through the ponds *i.e.* the outflows for each time interval equal the inflows.

Pond characteristics, such as depth, area, reed bed and shape are considered in the pond nodes. Multiple catchments can contribute to a pond, and pond links are also defined. Mixing factor patterns and dilution factors are also set which will affect the mass balance.

2.4 Validation

To gain confidence in the hydrology engine, an XP-RAFTS model was prepared using the same catchment and rainfall data. The peak flow outputs were then compared to those generated in the STORM Pesticide model. The results in Table 1 highlight the good correlation between XP-RAFTS and the STORM Pesticide model.

Table 1. Comparison of XP-RAFTS and STORM Pesticide peak flows.

Storm event	XP-RAFTS peak flow	STORM Pesticide peak flow
1 year 15 minute storm	3.96 m^3/s	3.99 m^3/s
5 year 15 minute storm	7.23 m^3/s	6.74 m^3/s
10 year 15 minute storm	8.49 m^3/s	10.79 m^3/s

3 PESTICIDES

A total of 36 pesticides have been included in the STORM Pesticide Model for assessment. Where possible Australian guidelines are used to determine compliance with drinking water and ecosystem protection criteria. In the absence of Australian guidelines, we either adopted an appropriate international guideline or derived a new guideline based on published guideline derivation protocols.

Of the 36 pesticides (active ingredients) proposed for use, only 5 had ANZECC guidelines for the protection of freshwater ecosystems. In the absence of any Australian guidance, guidelines were derived for the remaining 31 pesticides using the Canadian Protocol for the Derivation of Guidelines for the Protection of Aquatic Life. For assessment of compliance with Drinking Water Guidelines, a guideline hierarchy was used consisting of the Australian Drinking Water Guidelines, the World Health Organisation (WHO) Drinking Water Guidelines, or the European Union (EU) Drinking Water Guidelines. Since the EU guidelines contain a catch-all requirement of 0.1 µg/L for any pesticide, this was the default drinking water guideline level in the absence of Australian or WHO guidelines.

The application rate, and application surface (*e.g.* fairways and tees), K_{OC} (a "stickiness" factor) and degradation half-life are defined for each pesticide. The runoff concentration is then assessed against the specific guideline values provided for that pesticide.

4 MODEL OUTPUTS

A number of outputs are provided by the model for the final outflow as well as individual ponds and catchments for analysis. Figures 2 below describes pesticide concentrations in a particular water body including the inflow, outflow and average concentrations in relation to the outflow hydrograph. In this case it is for a high flow condition which results in the outflow concentration closely aligned to the average. Typical storm events would see the 3 distinct graphs pending the volume and shape of the water body being assessed.

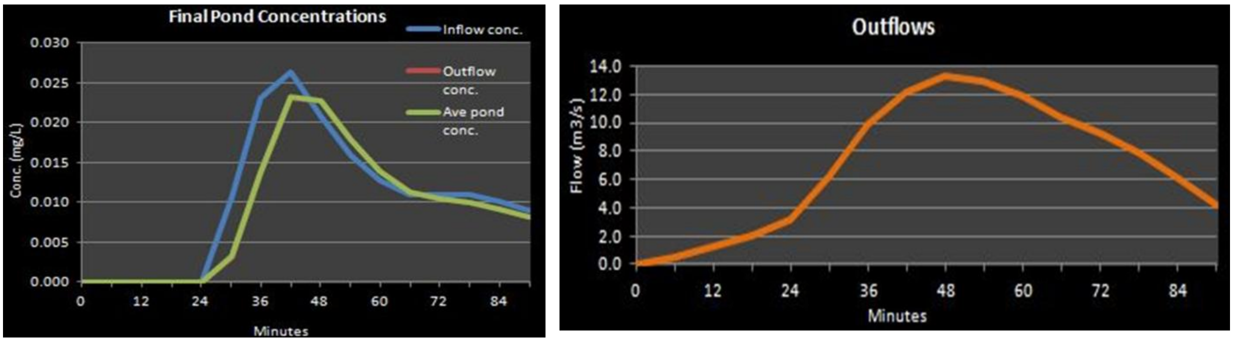
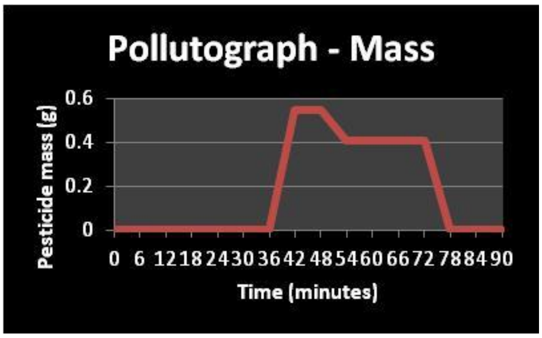


Figure 2. STORM Pesticide Model, Example Outputs from the final flows.

Figure 3 describes the pesticide runoff of an individual catchment in pollutographs on a mass and concentration basis. This allows assessment down to the individual catchment basis for calibration and investigations which is more critical for sites that have multiple catchments and water bodies.



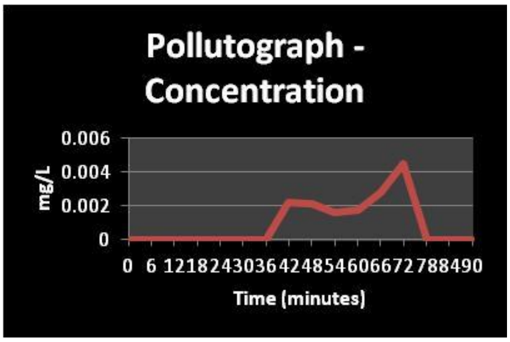


Figure 3. STORM Pesticide Model, Example Outputs from the Catchment Nodes

5 SUMMARY

The STORM Pesticide Model is a useful tool for assessing compliance with drinking water guidelines. The pesticides proposed for use, and the application controls, if any, to apply to each pesticide, can be considered for inclusion on planning controls for sites such as golf courses and sporting fields.

The Model combines the two specialist fields of hydrology and fate and transport of pesticides. This was undertaken to accurately predict the concentration of pesticide runoff from a given site which contains multiple ponds that facilitate mixing and dilution prior to discharge to a sensitive water body. The two fields of hydrology and fate and transport of pesticides have previously been treated in isolation of each other. The STORM Pesticide model is a first in combining the two specialties to ascertain a realistic prediction of pesticide concentration at the discharge location.

Research into expert opinion and algorithms concerning the fate and transport of pesticides was extensive and includes international benchmarks on water quality guidelines. Combining the information garnered through the research process to address the existing knowledge gap.

Creation of a user friendly model which can be used by asset owners to aid the decision making process of frequency and quantity of pesticides to apply related to the rainfall intensity forecasting by the Bureau of Meteorology will be an invaluable tool for sensitive receiving environments. Users can be confident in the results with an extensive peer review by national and international experts.

6 ACKNOWLEDGMENTS

Numerous parties have been involved in the formulation of the STORM Pesticide model. In particular, the environmental consultancy Ecos Environmental provided specialist chemical advice regarding appropriate algorithms for use in the development of the model to accurately calculate fate and transport of pesticides. Storm Consulting also worked closely with the consultancy Atura who are specialists in soil health and risk management. Melbourne Water are a significant stakeholder and have provided extensive review of the model, both internally and externally through renown national and international experts.

REFERENCES

[1] O’Connor N, Stevens D, Wiese R, Eastern Golf Club Tier 2 Risk Assessment, 2012.